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Twenty-Year Growth of Ponderosa Pine Saplings Thinned to Five Spacings in Central Oregon

James W. Barrett

Author

JAMES W. BARRETT is research forester at the Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, Oregon.

Abstract

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Diameter, height, and volume growth and yield are given for plots thinned to 1000, 500, 250, 125, and 62 trees per acre in a 40- to 70-year-old stand of suppressed ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) saplings in central Oregon. Trees averaged about 1-inch in diameter and 8 feet in height at the time of thinning. Considerations for choosing tree spacing for precommercial thinning in this type of stand are discussed.

Keywords: Thinning effects, stand density, precommercial thinning, ponderosa pine, *Pinus ponderosa*.

Summary

Tree spacing and understory vegetation had pronounced effects on diameter, height, and volume increment in a 40- to 70-year-old stand of suppressed ponderosa pine saplings in central Oregon. Trees averaged about 1 inch in diameter and 8 feet in height before thinning. At the widest spacing, with understory vegetation controlled, trees grew an average of 0.47 inches in diameter per year compared to only 0.13 inch at the narrowest spacing where understory vegetation was left to develop naturally.

Stand density and understory vegetation have had significant effects on height growth throughout 20 years of observation following thinning. Understory vegetation has had the greatest effect on height growth at the wider spacings, reducing growth from 15 to 50 percent during some periods.

Twenty years after thinning, low density plots contain less wood fiber than high density plots. On the other hand, widely spaced trees are much larger than narrowly spaced trees and collectively are now producing almost as much wood volume annually as high density plots.

Even though most of the trees left after thinning were 70 years old, stagnated, and suppressed by overstory, they have responded well to overstory removal and release, and trees at the three widest spacings appear capable of producing a usable crop of timber despite their advanced age.

Introduction

Millions of acres of commercial ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest land east of the Cascade Range in Washington and Oregon have a dense understory of suppressed trees overtopped by mature trees ready for harvest (fig. 1). In most areas where the overstory has been harvested, trees are being thinned, although some areas are being left to develop without thinning. Past research in the Pacific Northwest by Mowat (1953, 1961) and Barrett (1963, 1968, 1970) and personal observations have now convinced most managers that thinning overstocked stands after overstory harvest is necessary.

Managers prefer precommercial thinning to spacing that will result in a salable product the next time the stand must be thinned. If conservative spacing is selected for precommercial thinning on the assumption that there will be a market for roundwood in the future, and this market does not occur, a second precommercial thinning may be necessary. Constantly escalating costs of precommercial thinning add to the importance of selecting a realistic spacing on the first thinning. Leaving too many trees can be just as poor a choice as leaving too few. Leaving too few trees also forfeits some wood production before the site is completely occupied by tree roots and crowns. Many managers concentrate on producing trees of a certain size in a given time and want to know how many trees will reach the target diameter.

This spacing study is one of several established in ponderosa pine in the Pacific Northwest in the late 1950's and early 1960's. It is similar in design to the Methow study in north-central Washington (Barrett 1981), and some results of the two studies will be compared. The intent of studies of this kind was to provide forest managers with enough information from different treatments so they could choose tree spacing that would yield products compatible with management objectives. This is one reason for the widely divergent spacings in this study.

Figure 1.—Mature ponderosa pine stand with a dense, suppressed 40- to 70-year-old sapling understory before thinning to various densities.

Experiments in managing young, suppressed stands in the Pacific Northwest have changed over the past 40 years. The first experiments usually involved two plots, one thinned to a conservative spacing of 6 or 9 feet, the other left unthinned (Mowat 1953). Later, experiments in crop-tree thinning were established (Barrett 1969). All studies showed that suppressed, understory trees are capable of substantial response to thinning.

The full potential for diameter growth of second-growth ponderosa pine was not visualized until a study of free-growing trees was reported by Dahms and Silen in 1956.[1] They observed young trees free from competition growing at the rate of 6 to 7 inches per decade. They also found that heavy competition from brush reduced the growth rate to about 3 inches per decade. Thus, a tentative rate for maximum diameter growth was suggested and the importance of brushy understory competition was established. This work by Dahms and Silen suggested that the next thinning study should sample a wide range of spacings and should attempt to quantify the effect of brush competition on tree growth.

The Methow study, established about 4 years later, tested spacings of 9.3, 13.2, 18.7, and 26.4 feet as well as growth in unthinned plots (Barrett 1981). It showed that dense, suppressed ponderosa pine responded to increased space with more diameter and height growth. This study also showed that wider spacings produced large diameter trees in 20 years after thinning but that very wide spacings (26.4 feet) where the understory is predominantly pine grass can sacrifice substantial yields of wood fiber during the early part of a rotation.

This paper presents 20-year results from a spacing study in central Oregon. It was designed to give managers a wide range of alternatives for spacing in dense, suppressed sapling stands. The main objectives of the study are to determine:

1. Rates of diameter and height growth with various spacings.
2. Effects on tree growth of competition from understory vegetation.
3. Effect of spacing on periodic volume increment and yield.
4. Growing time after thinning needed to produce trees of usable sizes at various spacings.

Previous results from this study have been reported by Barrett (1965, 1970, 1973).

[1] Walter G. Dahms and Roy R. Silen, "An Informal Study of Free-growing Ponderosa Pine Trees." Unpublished report on file at Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, Oregon, 1956.

The Study Area

This spacing study is 35 miles southwest of Bend, Oregon, in the Pringle Falls Experimental Forest. Access to the study area is usually easy from May 15 to October. Plots are well marked and a map of the area may be obtained from the USDA Forest Service Silviculture Laboratory in Bend. Interested people are encouraged to visit the study plots.

Before the study was installed the stand consisted of old-growth ponderosa pine, averaging 17,000 board feet per acre with a 40- to 70-year-old suppressed sapling understory typical of thousands of acres of pine forests in central Oregon. Saplings averaged 1 inch in diameter, 8 feet in height, and 7,000 stems per acre. There were about 20 overstory trees per acre, averaging 850 board feet per tree. Ground vegetation consisted mainly of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), and greenleaf manzanita (*Arctostaphylos patula* Greene). Scattered plants of Ross sedge (*Carex rossii* Boott) could be found over the whole experimental area. The plots are in a transition zone between ponderosa pine/bitterbrush-manzanita/sedge and ponderosa pine/bitterbrush-snowbrush/sedge plant communities (Volland 1976).

Study plots are on an east-facing slope at 4,400 feet elevation and cover approximately 160 acres. Annual precipitation averages 24 inches, 85 percent of which falls between October 1 and April 30. A snowpack of 24 inches is common from January to March. Daytime temperatures during the growing season are cool with occasional frosts at night. Site index of old-growth pine in the area indicates a height of 78 feet at age 100 (Meyer 1961). The Lapine, Shanahan intergrade soil, a Typic Cryorthent, was developed in dacite pumice originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. The pumice averages 33 inches deep and is underlain by a sandy loam paleosol developed in older volcanic ash containing cinders and basalt fragments.

Experimental Design and Methods

Study design consists of 30 rectangular 0.192-acre plots, 79.2 by 105.6 feet (fig. 2). Each plot is surrounded by a buffer strip 33 feet wide which is treated the same as the inner plot. A plot contains 192 milacres and is divided into 12 subplots of 16 milacres as indicated in figure 2. This arrangement aided in selecting leave trees evenly distributed throughout the plot. In addition, it allowed easy growth comparisons of the largest diameter, evenly distributed trees within subplots.

Plots were thinned to average spacings of 6.6, 9.3, 13.2, 18.7, and 26.4 feet. Treatments contained the following numbers of trees:

6.6 feet, 192 trees per plot (1,000 trees per acre) (fig. 3)
9.3 feet, 96 trees per plot (500 trees per acre)
13.2 feet, 48 trees per plot (125 trees per acre) (fig. 4)
18.7 feet, 24 trees per plot (125 trees per acre)
26.4 feet, 12 trees per plot (62 trees per acre) (fig. 5)

Each spacing was replicated six times. Understory vegetation was removed by herbicides and mechanical means approximately every 4 years on three of the six replications.[2] A buffer area one-half chain wide around each plot was treated the same as the inner plot.

[2] Statistically, the experiment is a split-plot experiment. Whole-plot treatments are arranged as a 5-by-2 factoral in a completely randomized design. Whole-plot treatments are replicated three times. Split-plot treatments are time periods of remeasurement after installation. Five periods of 4 years each were used. Analysis of variance was used to judge the significance of treatment effect. The period effects were partitioned into orthogonal polynomial effects in order to look at the relationships of responses over time.

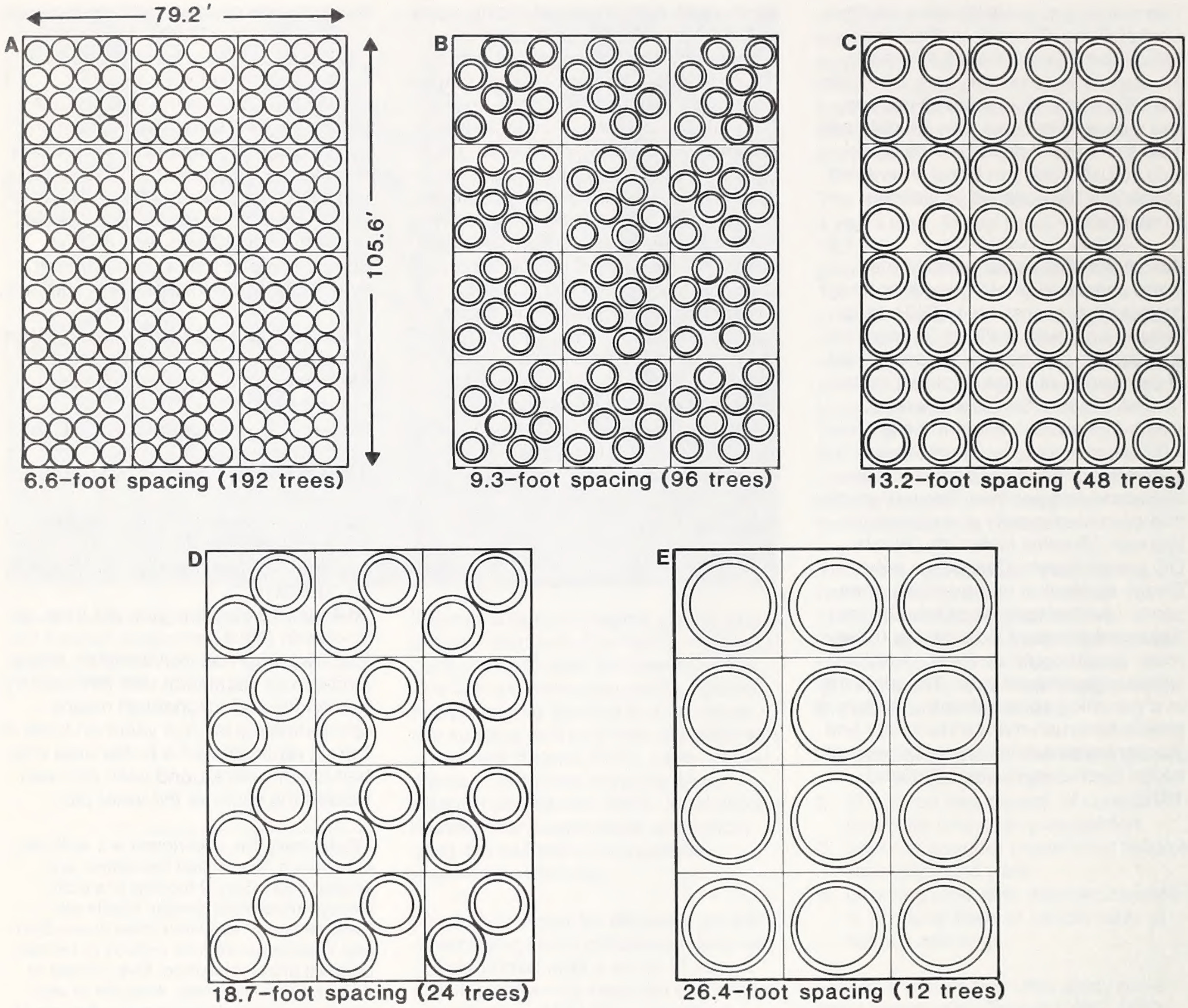

Figure 2.—Diagramatic sketch of tree location at five spacings in 0.192-acre full plots and 16-milacre subplots. Outer circles represent average crown size 20 years after thinning where understory vegetation was controlled; inner circles where vegetation was allowed to develop naturally.

Figure 3.—Plot thinned to 6.6-foot spacing, with understory vegetation controlled.

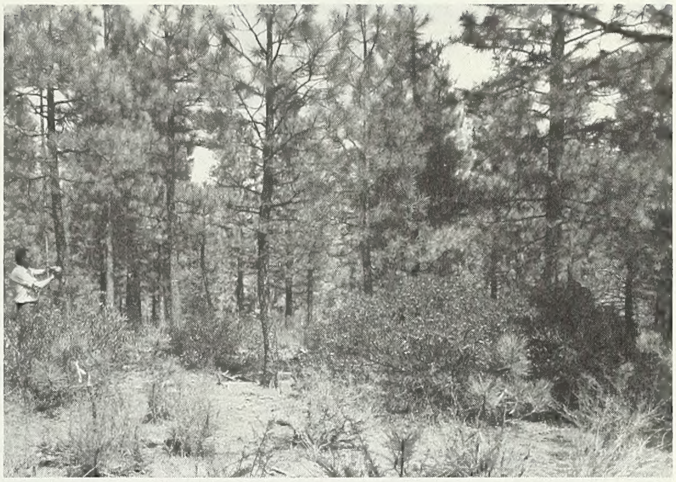

Figure 4.—Plot thinning to 13.2-foot spacing, with understory vegetation allowed to develop naturally. Manzanita brush in right foreground is 5 feet high.

Some understanding of tree distribution and crown closure for various spacings and vegetation treatment can be gained by comparing sketches in figure 2. Although trees left were sometimes not in the exact location for equal spacing, they were never closer than two-thirds the distance of treatment spacing. Crown closure 20 years after thinning varied from 86 percent where trees were 6.6 feet apart and vegetation was controlled to only 18 percent where trees were 26.4 feet apart and vegetation was not controlled.

Logging of overstory and thinning of saplings was started in the fall of 1957 and completed the fall of 1958. Thus, there was one growing season between thinning and initial measurement on some plots and up to two seasons on others. The one-year delay in completing logging and thinning affected all spacings and did not inadvertently bias growth measurements. All recent logging and thinning slash was removed from the plots and burned.

Diameters and heights of all trees were measured in the fall of 1959 and every four growing seasons for the next 20 years. Diameters were measured with a steel tape to the nearest one-tenth inch, and heights with a sectioned aluminum pole to the nearest one-tenth foot.

Tree volume for this report was computed using an improved volume equation for second-growth ponderosa pine recently developed by DeMars and Barrett.[3] The data base for this equation was obtained from north-central Washington and central and eastern Oregon. Therefore, volume estimates presented here will differ from those in previous publications on this study (Barrett 1970, 1973).

Percent cover of understory vegetation on 15 plots was measured by systematic sampling of 100 points per plot (Heady et al. 1959).

[3] Donald J. DeMars and James W. Barrett. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

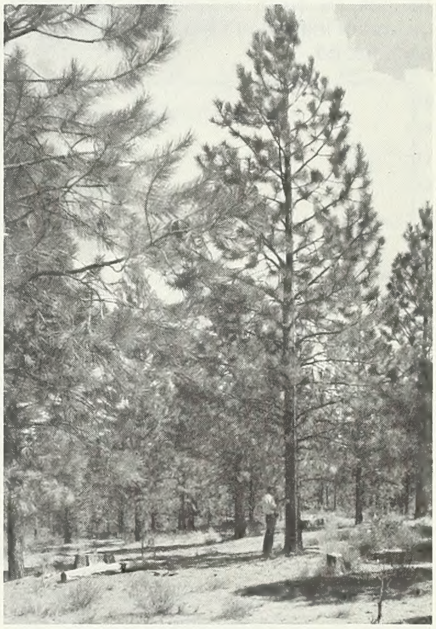

Figure 5.—A dominant tree on a plot thinned to 26.4-foot spacing. In 1959, just after thinning, this tree was 2 inches in diameter and 10 feet tall. Twenty years later it was 13.8 inches in diameter and 45 feet tall.

Results and Discussion

Diameter Growth

Table 1—Results of analysis of variance

Variable	Spacing	Vegetation	Period: Linear[1]	Period: Quadratic[2]	Period: Lack of fit[3]	Spacing x period interaction	Vegetation x period interaction
Diameter increment	**	**	**	**	n.s.	**	**
Height increment	**	**	**	**	**	**	**
Volume increment	**	**	**	n.s.	**	**	**
Basal area increment	**	**	**	**	*	n.s.	**
Diameter	**	**	**	**	**	**	**
Height	**	**	**	**	**	**	**
Volume	**	**	**	**	n.s.	**	**
Basal area	**	**	**	**	**	**	**

n.s. = not significant; * = significant at 5-percent level of probability (significant); ** = significant at 1-percent level of probability (highly significant).

[1] The linear component of period isolates the variation accounted for if a straight line is fit through the data.
[2] The quadratic component of period isolates the variation accounted for if a second degree curve is fit through the data.
[3] Lack of fit isolates additional variation not accounted for by the linear and quadratic components.

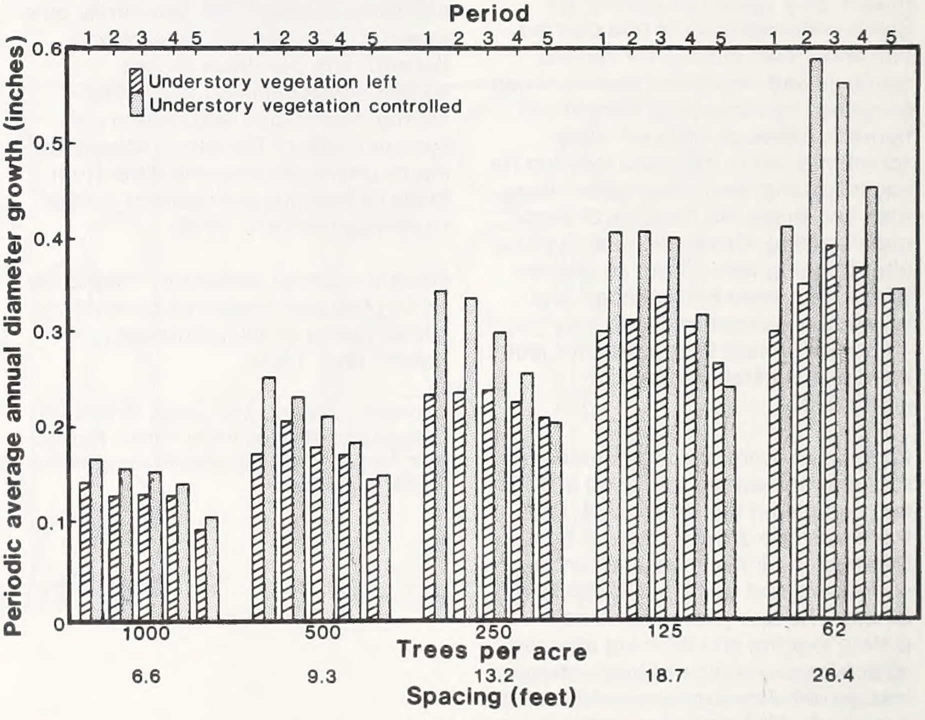

Figure 6.—Periodic annual diameter increment during five 4-year measurement periods. Increment is based on the average growth of individual trees living through each period.

Spacing and understory vegetation had highly significant effects on diameter growth (table 1). Widely spaced trees grew faster than narrowly spaced trees (fig. 6). During the 20 years of observation periodic annual diameter growth has averaged as follows:

Spacing	Trees per acre	Vegetation left	Vegetation controlled
Feet		*Inches*	
6.6	1000	0.13	0.15
9.3	500	.18	.21
13.2	250	.23	.29
18.7	125	.30	.35
26.4	62	.35	.47

Understory vegetation has had a pronounced deterrent effect on diameter growth especially at the wider spacings (fig. 6). This was most evident during the first three measurement periods and appears to have diminished in the last two. Severe drought during the last 4-year period may have influenced these relationships. Also, during this same period lack of snow cover and below freezing temperatures defoliated much of the ceanothus and some manzanita.

Although diameter growth at wider spacings increased during the first three periods, it has diminished since that time. This has been most evident and consistent during the last two periods of observation. A similar trend was observed in the Methow Valley study (Barrett 1981). This is probably due to increasing age and stand density (basal area).

Twenty years after thinning the effect of understory vegetation on average diameter is most evident at the wider spacings. For example, where 62 trees per acre were left, average diameter was 11.6 inches where the understory vegetation was controlled, compared to 9.1 inches where vegetation was allowed to develop naturally (fig. 7). Where 125 trees per acre were left, the comparison is 9.6 to 8.3 inches. If diameters are projected to 28 years after thinning, when trees may be merchantable, diameters are estimated to be:[4]

Spacing	Trees per acre	Vegetation left	Vegetation controlled
Feet		*Estimated d.b.h. (inches)*	
6.6	1000	5.3	5.5
9.3	500	6.4	6.9
13.2	250	8.2	8.8
18.7	125	10.1	11.0
26.4	62	11.4	13.5

If we look at these results in terms of management goals and existing stock level guidelines (Barrett 1979) we find that 500 trees per acre probably exceeds the stocking level that will produce usable round wood 8 inches in diameter in 28 years (fig. 7). On the other hand, where 250 trees were left, average diameters have approached or exceeded maximum stocking at about 8 inches. Therefore, if supplying a round-wood market is the objective of the first commercial entry, it appears that no more than 250 trees per acre should be left (tables 2-6). Increment rates shown in figure 6 can be used to estimate the time needed for trees to grow to various diameters at the five stocking levels. Results of this study suggest that an acceptable initial number of trees to produce for a sawlog market on this site is between 125 and 250 trees per acre, although temporary losses in yield should be expected from a drastic reduction in the number of trees.

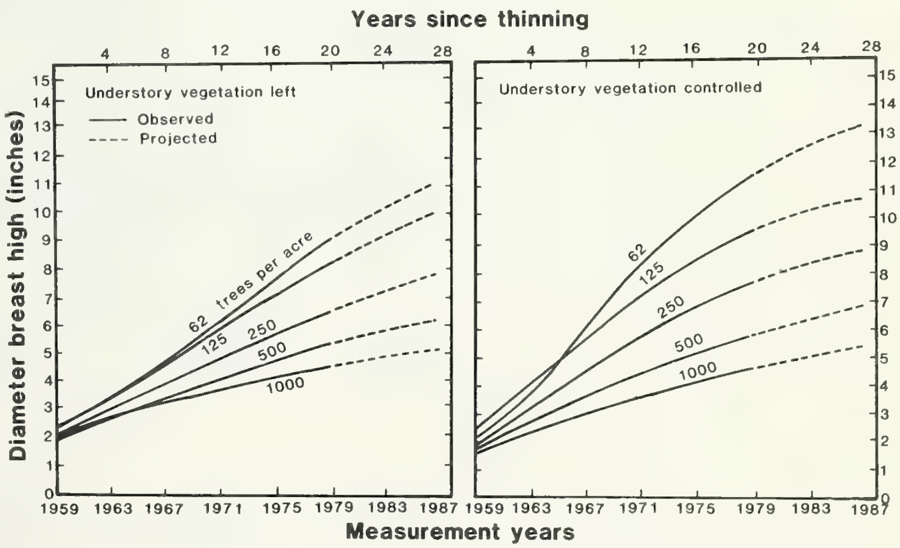

Figure 7.—Average stand diameter under five thinning treatments during 20 years of observation and estimates projected 8 years in the future, with vegetation left to develop naturally and vegetation controlled.

[4] Projections of tree diameter and basal area beyond 20 years after thinning were made by equations fitted to the data and by examining trends of diameter and basal area growth. Unforeseen climatic changes during the next decade could influence these estimates.

Table 2—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 6.6-foot spacing (1,000 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
0.5	1	4.6	1	4.9
1	17	8.5	21	7.0
2	78	12.3	63	11.9
3	184	16.2	177	15.1
4	234	20.1	257	19.2
5	238	23.8	228	22.6
6	141	26.9	135	26.1
7	71	29.9	63	29.7
8	10	33.2	30	32.5
9			4	34.8
Total or average	974	21.3	979	20.5
		Inches		
Quadratic mean d.b.h.	4.7		4.7	
		Square feet per acre		
Basal area	115.5		120.7	

Table 3—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 9.3-foot spacing (500 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
1	1	8.2	1	7.2
2	10	11.5	3	9.8
3	51	14.5	24	13.1
4	101	17.7	80	18.7
5	129	20.6	108	21.2
6	111	24.7	132	24.3
7	61	26.8	101	28.2
8	24	31.3	43	32.1
9	7	37.6	4	33.7
10			2	42.0
Total or average	495	21.6	498	23.5
		Inches		
Quadratic mean d.b.h.	5.5		5.9	
		Square feet per acre		
Basal area	80.8		93.8	

Table 4—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 13.6-foot spacing (250 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
3	7	12.8		
4	19	17.3	3	16.9
5	48	20.2	14	22.0
6	47	23.3	42	25.4
7	57	27.4	67	28.7
8	45	31.1	59	31.9
9	19	32.3	36	35.5
10	4	35.2	14	34.6
11			2	34.8
12			4	41.3
Total or average	246	25.2	241	29.8
		Inches		
Quadratic mean d.b.h.	6.7		7.7	
		Square feet per acre		
Basal area	60.1		78.5	

Table 5—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 18.7-foot spacing (125 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
4	1	12.5	2	15.5
5				
6	5	21.2	2	17.5
7	35	27.7	10	28.2
8	38	28.7	24	30.7
9	29	33.7	26	35.2
10	12	36.9	24	36.7
11	3	40.9	26	40.3
12	2	38.0	9	43.5
13			2	31.9
Total or average	125	30.4	125	32.2
		Inches		
Quadratic mean d.b.h.	8.3		9.0	
		Square feet per acre		
Basal area	47.2		62.6	

Table 6—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 26.4-foot spacing (62 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
6	5	18.3		
7	4	25.4	1	18.8
8	10	28.8	1	27.0
9	17	31.6	4	30.9
10	14	33.4	9	33.0
11	10	36.3	16	33.1
12	2	38.0	16	38.5
13			10	44.5
14			5	43.7
Total or average	62	31.2	62	36.9
		Inches		
Quadratic mean d.b.h.	9.2		11.7	
		Square feet per acre		
Basal area	28.5		45.9	

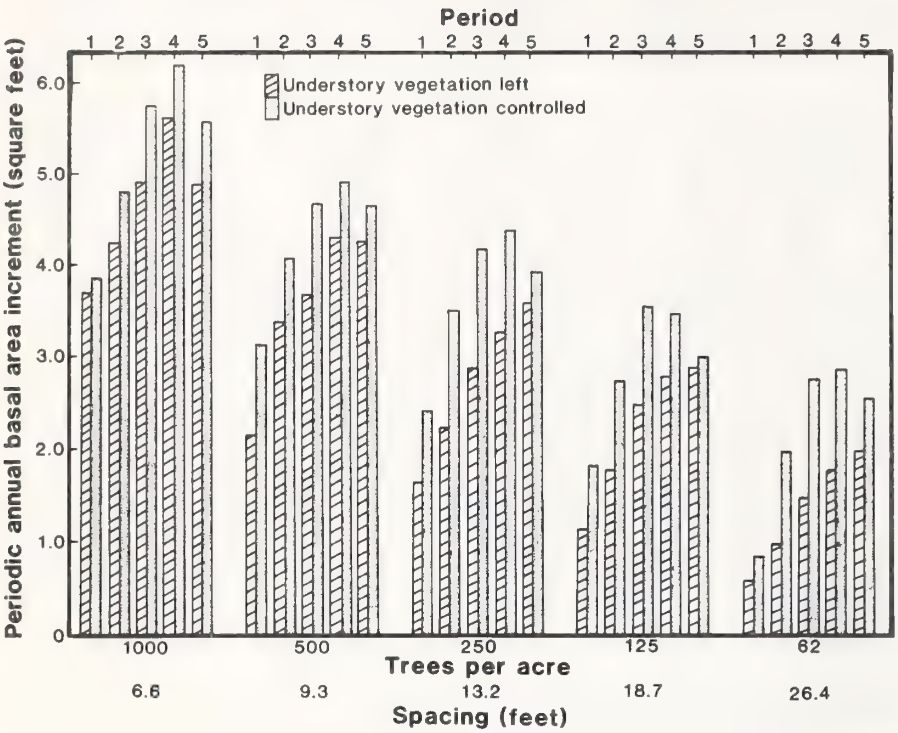

Figure 8.—Periodic annual basal area increment during five 4-year measurement periods.

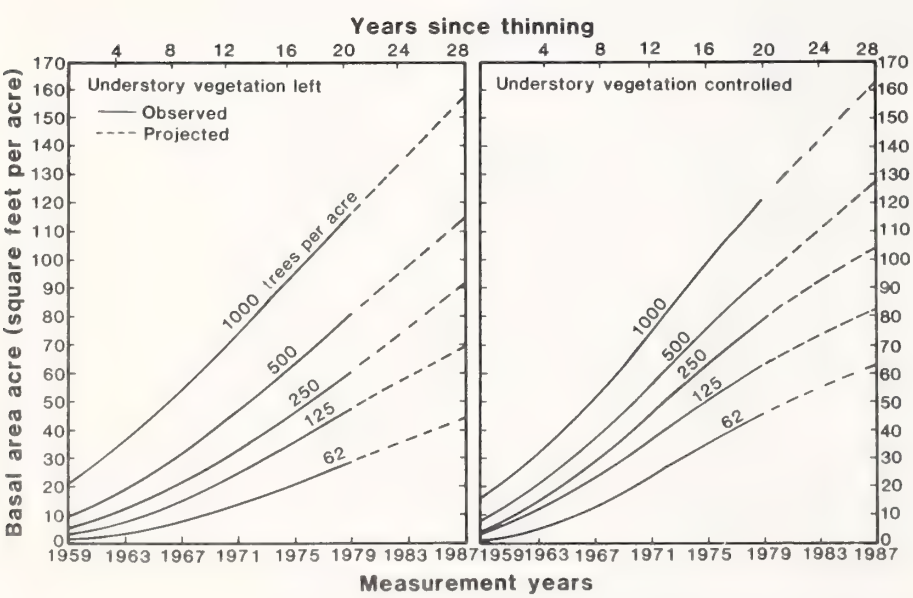

Figure 9.—Net basal area attained during 20 years after thinning and predicted 8 years in the future, with vegetation allowed to develop naturally and vegetation controlled.

Basal Area

Basal area was significantly and positively correlated with spacing (table 1). During the first four periods basal area increment increased steadily in all treatments where understory vegetation was controlled, with one exception (fig. 8), but during the last period increment declined in all treatments. Where understory vegetation was left to develop naturally periodic basal area increment increased at all spacings during the first four periods but declined in the fifth period at only the two narrowest spacings.

Periodic annual increment ranged from a high of 6.2 square feet per acre during the fourth period at the closest spacing to a low of 0.6 square foot at the widest spacing in the first period (fig. 8). The greater increments in basal area occurred where the initial basal area was greater. Understory vegetation consistently reduced basal area increment at all spacings. This effect was most pronounced at the wider spacings, where reductions of around 50 percent occurred during some periods.

Basal area at the closest spacing has accumulated more than 110 square feet during the 20 years after thinning, compared to only 25 square feet at the widest spacing where understory vegetation was left to develop naturally (fig. 9). In another 8 years (28 years after thinning) basal area at the closest spacing could be an estimated 160 square feet. This density could predispose the stand to a bark beetle infestation if trees attain the size for optimum insect development (Sartwell 1971).

Height Growth

Both stand density and understory vegetation had significant effects on height growth throughout the 20 years of observation (table 1). Trees at the widest spacing are growing about 1.5 feet per year where vegetation was controlled and only about 0.7 foot at the narrowest spacing (fig. 10). Understory vegetation is having the greatest effect at the wider spacings, reducing growth as much as 15 to 20 percent during some periods.

The reader should keep in mind that before thinning these trees were heavily suppressed by high density and overstory, and height growth was only a few inches per year. After thinning, roots needed time to grow and expand into space formerly occupied by those of cut trees. From figure 10 one might be tempted to conclude that trees in the two lowest densities (62 and 125 trees per acre) have reached maximum capacity for annual height growth. Reaching this growth rate capability apparently took about 12 years. Trees at higher densities may still be increasing in annual rate of growth, but additional time is needed to see if these denser spacings have reached maximum rate or will ever reach the rate attained by wider-spaced trees.

Because of the uneven pattern of past height growth (fig. 11), no attempt was made to project future height growth. Thus, volume growth could not be projected an additonal 8 years.

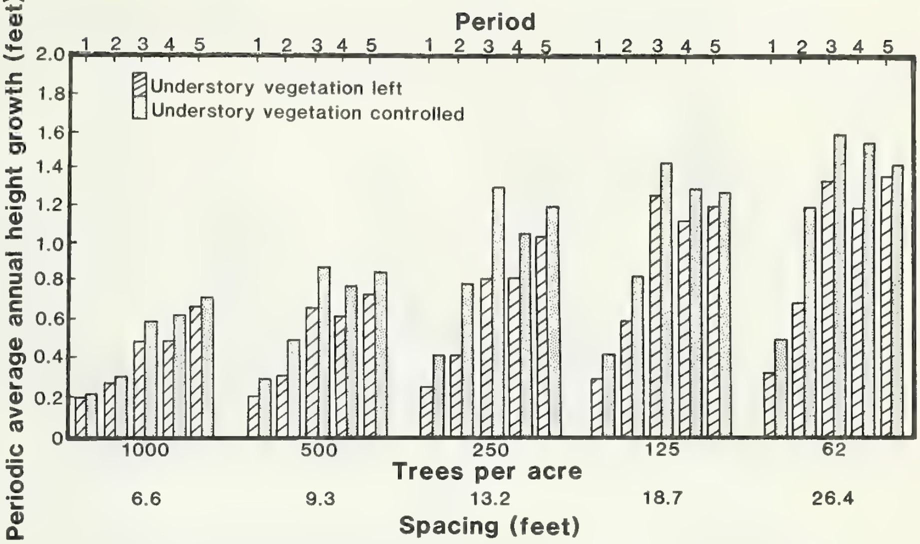

Figure 10.—Periodic average annual height growth during five 4-year measurement periods. Increment is based on the average growth of individual trees living through each period.

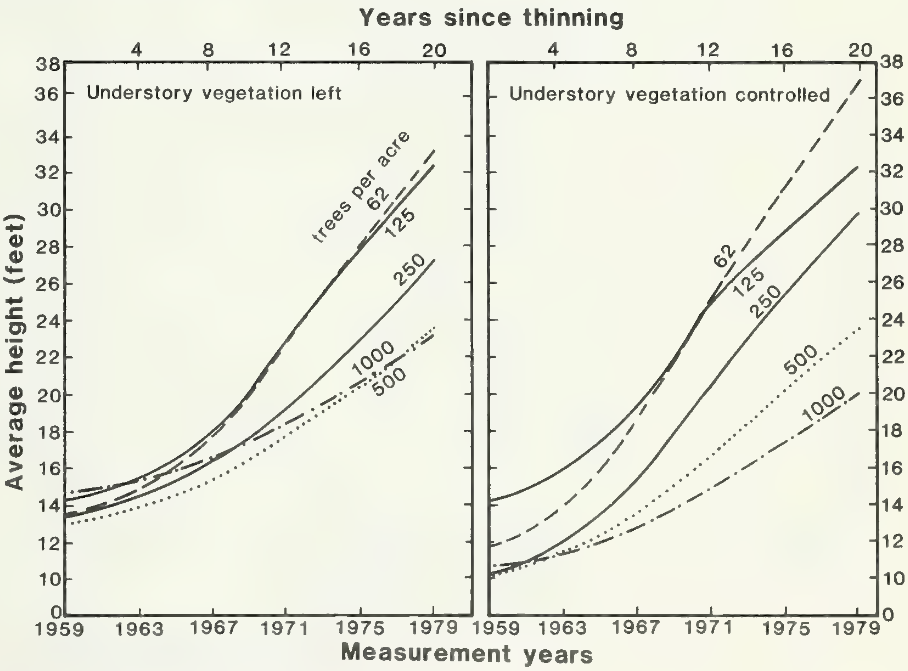

Figure 11.—Average tree heights during 20 years of observation. Averages are based on heights of trees living through each period, with vegetation left to develop naturally and vegetation controlled.

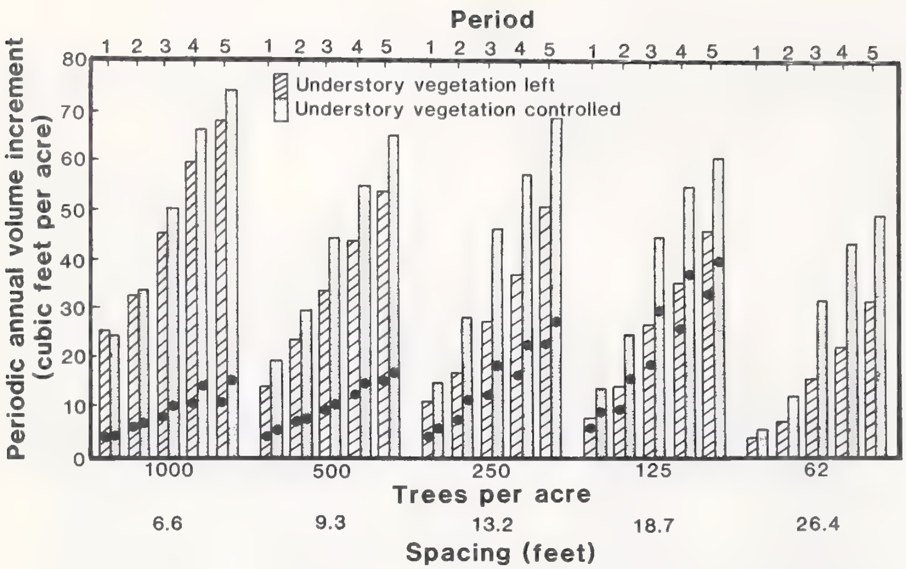

Figure 12.—Periodic annual net increment during five 4-year measurement periods. Bars show total increment for trees at each spacing. Points within bars show increment of the 62 largest well-distributed trees per acre within plots.

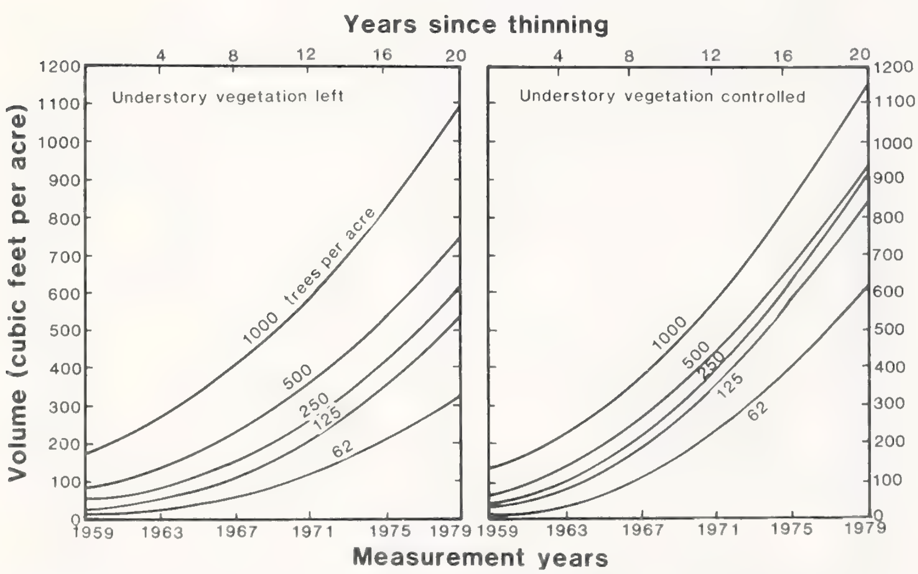

Figure 13.—Net yield of trees thinned to five stand densities, with vegetation allowed to develop naturally and vegetation controlled.

Mortality

There was no mortality at the widest spacings and it was minor at other spacings. Mortality ranged from 3.6 percent where 250 trees per acre were left to 0.4 percent where 500 trees per acre were left.

Since most of the trees that died were in the 1- and 2-inch diameter classes, the effect on gross volume increment was small. Since no mortality was observed during the first 4-year period and only two trees died during the last period, most of the mortality occurred between 1963 and 1975. The cause of tree deaths was unknown, although root rot (*Armillaria*) was suspected.

Volume Increment and Yield

The diameter at which ponderosa pine may be sawn into lumber differs with locale, but in central Oregon the lower limit is now about 9 inches at breast height. Since the majority of trees in this study are still below that size 20 years after thinning, yield and increment are examined here in cubic feet only.

Periodic annual increment (PAI)[5] has steadily increased over the 20 years of observation throughout all spacings tested (fig. 12). The highest annual increment measured during the last 4-year perod was about 75 cubic feet per acre per year at the 6.6 foot spacing where vegetation was controlled.

Although there was a consistent increase in PAI throughout the range of spacings it was most impressive at the wider spacings, where growth sometimes doubled from one period to the next. This was apparently due to rapid diameter and height growth where competition was low. Thus, increment rates on the low density plots are rapidly approaching those on the high density plots.

[5] Volumes may differ from previous publications because improved volume equations were used in this report. See footnote 3.

As might be expected, spacing has had a highly significant effect on PAI throughout the 20 years (table 1), but it is also notable that where vegetation was controlled, PAI has been similar at three spacings (9.3, 13.2, and 18.7 feet) during each of the last three measurement periods (fig. 12). This suggests that if competition from understory vegetation could be controlled by chemicals or prescribed fire during the first decade after thinning the same amount of wood fiber might be produced over a wide range of spacings.

The growth-depressing effect of understory vegetation on PAI throughout the 20 years was highly significant (table 1). This effect was much more pronounced at the wider spacings, where PAI was sometimes reduced one third to one half.

The greatest yield of wood was produced where the highest number of trees were left (1,000 per acre) (fig. 13). This yield, however, was on trees having an average diameter of only 4.7 inches 20 years after thinning. Where 500 trees per acre were left, average diameters were from 5.5 to 5.9 inches.

One important need in ponderosa pine management is a stocking guide that is relatively independent of age and site. Stand density index (Reineke 1933) is one of several promising alternatives. The data on volume increment in relation to stand density index and basal area presented in figures 14 and 15 represent another contribution to guidelines for stocking. Some workers, however, believe these relationships are not as clearcut as presented in figures 14 and 15; they believe that pattern of stand development is independent of age and site but that rate of development may not be.

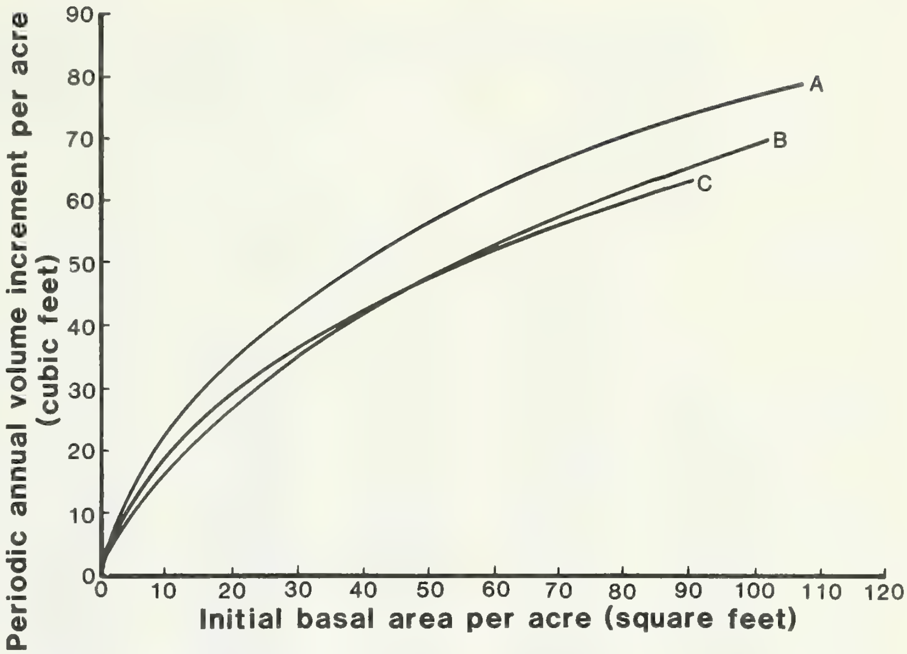

Figure 14.—Periodic annual volume increment in relation to basal area at the beginning of each growth period on two spacing studies.

A = Pringle Falls spacing study, understory vegetation removed
[$y = 103.89007\,(1-e^{-0.0094292x})^{0.6269498}$].

B = Pringle Falls spacing study, understory vegetation left
[$y = 107.948063\,(1-e^{-0.0075134x})^{0.7096307}$].

C = Methow study
[$y = 97.8675\,(1-e^{-0.007255})^{0.6115}$].

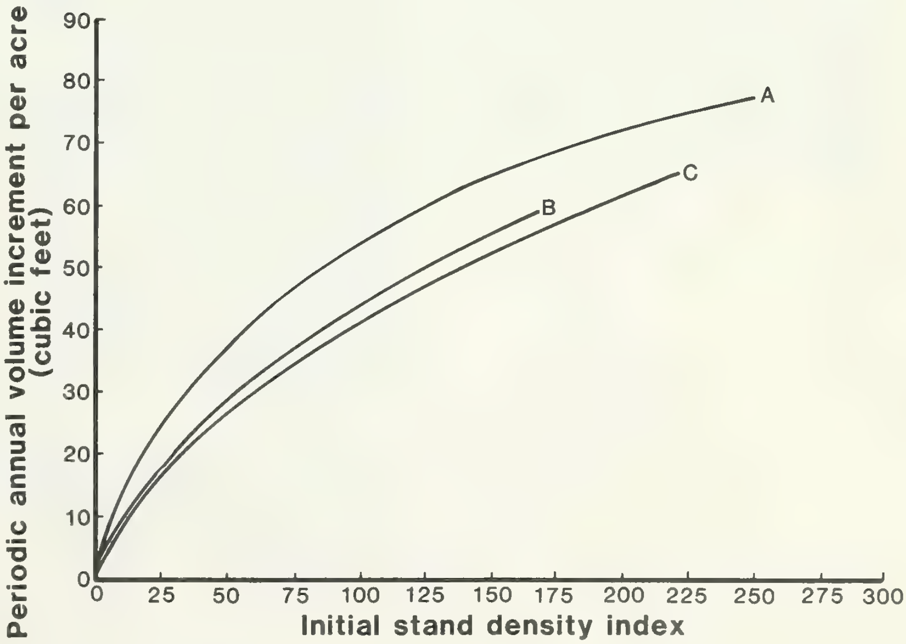

Figure 15.—Periodic annual volume increment in relation to stand density index (Reineke 1933) at the beginning of each growth period on two spacing studies.

A = Pringle Falls spacing study, understory vegetation removed
[$y = 89.0077\,(1-e^{-0.0065674x})^{0.6836723}$].

B = Pringle Falls spacing study, understory vegetation left
[$y = 111.596877\,(1-e^{-0.0029654x})^{0.6885196}$].

C = Methow spacing study
[$y = 74.7556\,(1-e^{-0.007018x})^{0.6772}$].

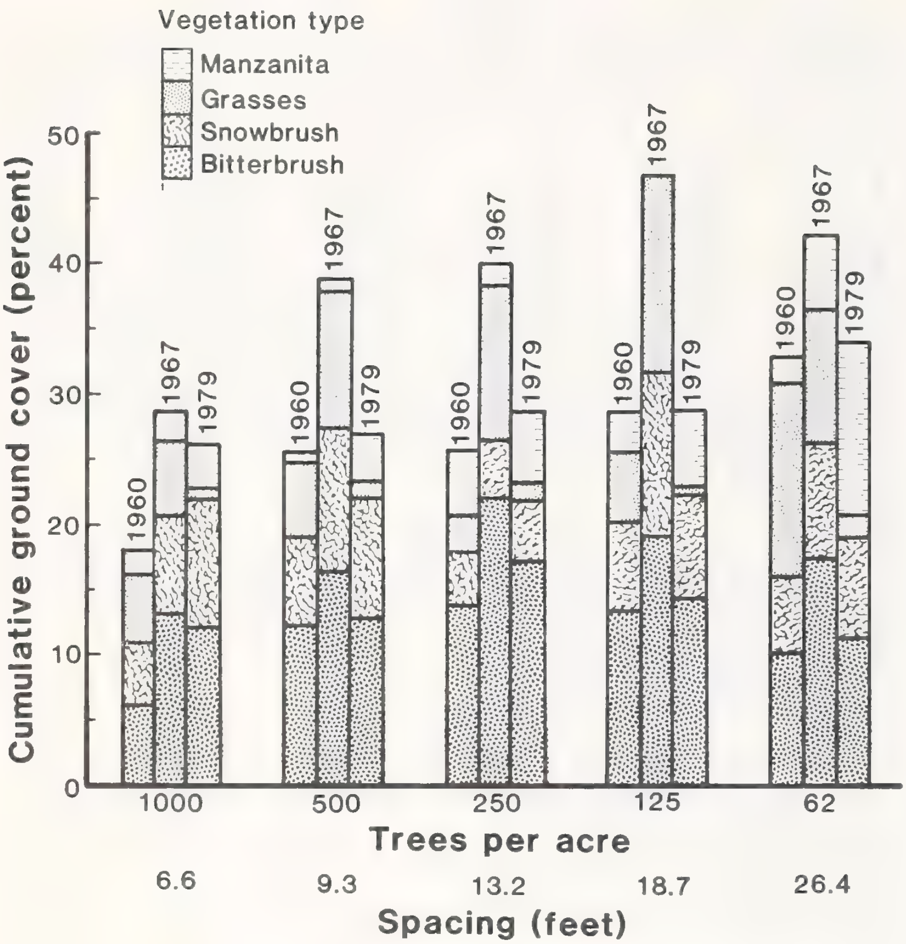

Figure 16.—Average percent of ground covered by understory vegetation in 1960, 1967, and 1979. Two growing seasons elapsed between overstory removal and thinning, and measurement of vegetation in 1960. Differences in the amount of vegetation cover among tree spacings may have developed before initial measurements were taken.

Effects on Understory Vegetation

Statistical tests showed that the amount of understory vegetation was affected by tree spacing (5 percent level of probability) only during 1967 (fig. 16). Cover percentages varied widely from plot to plot within treatments at the wide spacings, even in 1967, and were greater at other measurement dates. The first measurements of cover were not made until 1960. Figure 16 suggests that spacing was already having some effect on cover percentages, but this was not statistically significant.

Since controlling understory vegetation had a highly significant effect on diameter, height, and volume growth (table 1), and the spacing x vegetation interaction was highly significant, one might conclude that there must now be more vegetation present at the wider spacings than at narrow spacings. There may be, but our procedure for sampling understory vegetation apparently is not sensitive enough to detect existing differences in vegetative cover.

Results shown in figure 12 and table 7 suggest that trees sustained substantial losses in increment because of competition with understory vegetation. The growth-reducing effect is most evident at the wider spacings, where losses approach or exceed 50 percent (table 7). The lower losses of the last observation period could be the result of reductions in understory cover caused by climatic factors.

Oliver (1979) reported reductions in tree growth caused by brush competition in a similar experiment in a 12-year-old ponderosa pine plantation on a highly productive site in California. Where brush cover was near 100 percent, tree diameter was reduced by the equivalent of nearly 3 years of growth.

During the 1974-79 period two climatic extremes severely affected understory vegetation throughout central Oregon. During the winter of 1977-78 a drop in temperature to far below freezing, in the absence of snow cover, defoliated much of the manzanita and snowbrush. This cold period was followed by a severe drought the following summer which may have depressed cover percentages in 1979. Grasses also suffered; figure 16 shows a marked drop in grass cover in 1979. This depressing effect on growth of brush and grass species may have encouraged the growth of pine seedlings.

In 20 years, the pine reproduction that consisted of small seedlings at the time of thinning has also responded to additional growing space in the plots where understory vegetation was allowed to develop. Seedlings have increased in size and number and now constitute a notable part of the brush-grass competition. Numbers and sizes of small trees observed in 1979 were as follows:

	Excess trees per acre			
Spacing	Total	Below breast height	Above breast height	Average d.b.h. of trees above breast height
Feet				*Inch*
6.6	94	52	42	0.8
9.3	177	151	26	.9
13.2	698	656	42	.8
18.7	875	802	73	.8
26.4	1448	1141	307	.8

Whether the invasion of small trees in thinned stands becomes a problem in general practice depends largely on how the slash and understory vegetation are treated. Thinning slash is often mechanically crushed (Dell and Ward 1969) to reduce fire hazard. Young seedlings are often destroyed in this process or covered with slash. Also, prescribed burning or piling and burning destroys most unwanted seedlings.

Table 7—Losses of volume growth in suppressed sapling ponderosa pine thinned to five spacings and competing with understory vegetation, central Oregon

	Years after thinning				
Spacing	0-4	5-8	9-12	13-16	17-20
Feet			*Percent*		
6.6	0	4	10	11	9
9.3	27	20	24	21	17
13.2	27	40	41	35	26
18.7	45	44	41	36	25
26.4	33	56	52	50	37

Conclusions

Managers are frequently tempted to apply results from studies such as this to a broader geographic area than can be justified. This often happens because it is the only information available and some knowledge seems better than none. Studies such as this were not designed to predict growth and yield over a wide geographic area but to look at the relationship of tree spacing, understory vegetation, and growth and yield. It is not appropriate to use the information presented here, for example, to predict growth and yield in the Ochoco Mountains or on a low site in the Deschutes National Forest. Information on which to base such predictions would require intensive representative replication of this study, and funding to do this was not available when this study was installed. Thus, caution is advised in using these results to predict growth on other sites, initial stand sizes, and plant communities. Comparisons should be chosen carefully. A common error is to compare growth of recently thinned small pole stands to growth immediately after thinning in this study of saplings. Diameter growth in pole stands is usually much less than in sapling stands because density (basal area) is much higher and crown ratios frequently poorer. Another common mistake is to compare results of this study to a situation where four or five overstory trees per acre are left and the sapling understory is thinned. Even a few overstory trees per acre can be surprisingly effective in suppressing growth on thinned understory (Barrett 1969). On the other hand, as Bruce (1977) suggests, "The scientist should not hide behind the facile caveat 'under the conditions of this test these outcomes were observed.' His interpretation should include his best opinion about practical application." The discussion that follows is my best interpretation of application.

Results from this study may be used in several ways. First, they quantify the effects of spacing and understory vegetation on growth and give the manager some idea of gain from control of tree density and vegetation. Second, they provide an estimate of the time needed to grow trees to commercial sawlog size. And third, they provide an estimate of cubic volume yield 20 years after thinning. In addition, study results document the extent of mortality in this thinned stand. They also document the fact that severly suppressed trees will respond to release at 40 to 70 years of age and grow at rates observed in much younger trees. How long these growth rates continue is not known, but since ponderosa pine is a long-lived species we can assume that age will not be a serious deterrent to growth before trees at the wider spacings reach target diameters of 20 to 24 inches.

It is apparent from these results that the time required to reach a target diameter is affected by initial spacing and the amount of understory vegetation present. The lower the density of tree and understory vegetation the shorter the time needed to produce trees of specific sizes.

There appears to be a cost in yield if size is an objective. To produce larger trees in a given time, there must be fewer trees. Consequently growing stock is less and yield is reduced. Figure 17 shows this relationship for this study. Also strikingly evident in this figure is the effect of understory vegetation on yield, although long-term yield will probably not be reduced in the same proportion as shown for the first 20 years after precommercial thinning. At the two widest spacings yield has been reduced 34 and 45 percent. Evidently, soil not occupied by tree roots was invaded by roots of understory vegetation. Observations in natural stands suggest that brush competition persists until crowns begin to close and trees become the superior competitors; the brush then dies or becomes less competitive. This observation suggests that brush control several years after thinning and again about 5 years later may enhance stand growth. On some sites, after trees reach 5 inches d.b.h., prescribed fire is a promising method of subduing competitive brush early in the rotation (Martin and Dell 1978).

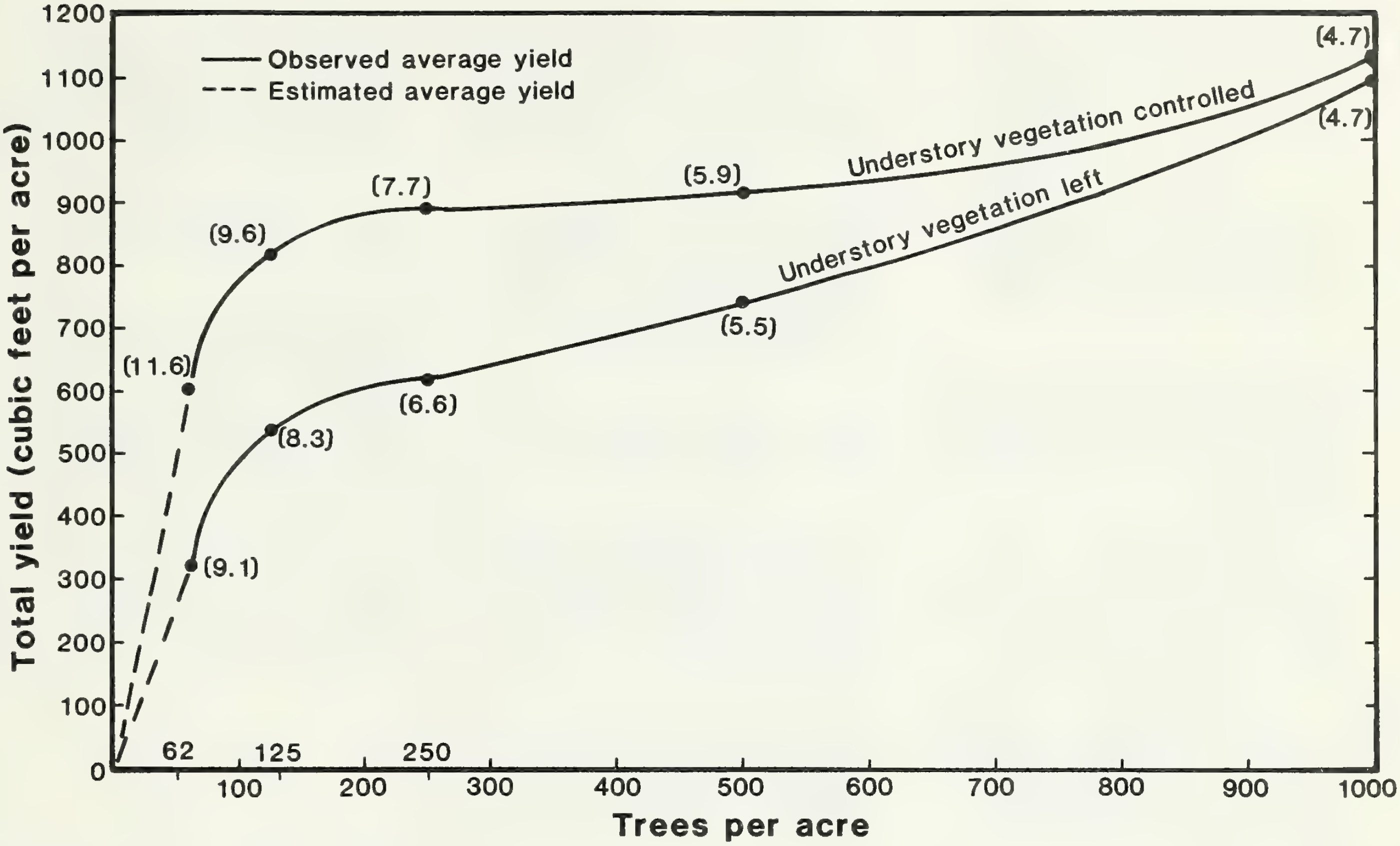

Figure 17.—Yield of suppressed ponderosa pine saplings 20 years after thinning to five densities, with vegetation allowed to develop naturally and vegetation controlled. Average diameters for each density (inches d.b.h.) shown in parentheses.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 acre = 0.404 7 hectare
1 square foot/acre = 0.229 6 square meter/hectare
1 cubic foot/acre = 0.069 97 cubic meter/hectare

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Diameter, height, and volume growth and yield are given for plots thinned to 1000, 500, 250, 125, and 62 trees per acre in a 40- to 70-year-old stand of suppressed ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) saplings in central Oregon. Trees averaged about 1-inch in diameter and 8 feet in height at the time of thinning. Considerations for choosing tree spacing for precommercial thinning in this type of stand are discussed.

Keywords: Thinning effects, stand density, precommercial thinning, ponderosa pine, *Pinus ponderosa*.

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Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

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